A multiscale nested modeling framework to simulate the interaction of surface gravity waves with nonlinear internal gravity waves

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LONG-TERM GOALS

Our long-term goal is to develop a multiscale nested modeling framework that simulates, with the finest resolution being centimeter scale, surface mixed layer processes arising from the combined actions of tides, winds and mesoscale currents. Issues related to nesting of models designed to study phenomena at different scales will be studied, including how to nest the regional and nonhydrostatic SUNTANS model within the global HYCOM model, as well as nesting of small-scale LES codes into the SUNTANS model.

OBJECTIVES

As a model problem of mixed-layer dynamics involving numerous physical processes acting over a wide range of spatio-temporal scales, we will focus on the interaction of surface and internal gravity waves in the South China Sea. Our objective is to study surface gravity wave evolution and spectra in the presence of surface currents arising from strongly nonlinear internal gravity waves. We will focus on understanding the impact of tidal, seasonal, and mesoscale variability of the internal wave field and how it impacts the surface waves.

APPROACH

We are focusing on the problem of modification of the wind-wave field by internal wave surface currents, a process that can be validated with both in-situ observations and synthetic aperature radar (SAR) imagery which shows distinct internal solitary wave (ISW) signatures throughout the South China Sea (Jackson et al. 2013). Despite advances in internal wave modeling of the South China Sea (Simmons et al. 2011) and SAR imaging techniques of ISWs (Xue et al. 2013), there is no predictive ability of ISW dynamics in the South China Sea owing to the computational expense associated with computing nonhydrostatic effects inherent to ISWs. Furthermore, extensive theory exists to explain the sea-surface expression of ISWs, but it is based on idealized internal wave theory and no three-dimensional models have been applied to understand or predict the surface wave field and how it interacts with the internal wave-driven surface currents. To this end, we are performing simulations with a series of nested models to understand the three-dimensional dynamics governing the interaction of surface and internal gravity waves. Specific question we are addressing include:

1) How well do weakly nonlinear ISW theories predict the evolution of ISWs in the presence of a variable mesoscale background field?
2) How does the wind-wave field evolve in the presence of surface currents driven by ISWs?
3) How does the surface gravity wave field above ISWs modify the mixing and dissipation in the mixed layer?
4) What specific parameters related to ISWs enhance or limit their impact on the surface gravity wave spectrum? How does this affect the detectability of ISWs in SAR imagery?
5) How does the seasonal variability of ISW currents impact the surface gravity wave spectra?

To simulate finescale processes related to surface gravity waves, a large-eddy simulation (LES) code that simulates turbulence-wave interactions on a wave-surface-fitted grid and a nonlinear wave-field simulation code is being employed (Yang et al. 2013, 2014). The LES code will be driven by currents from a high-resolution, nonhydrostatic, isopycnal-coordinate model based on SUNTANS (Fringer et al. 2006) that will simulate ISW evolution in the SCS. Although the SUNTANS model was applied to simulate ISWs in the SCS (Zhang et al. 2011), that implementation did not incorporate sufficient resolution to resolve the ISWs. In this proposal we will resolve the leading-order ISW dynamics by performing SUNTANS simulations in a limited region of the SCS using the nonhydrostatic isopycnal-coordinate method of Vitousek and Fringer (2014). Initial and boundary conditions for the isopycnal-coordinate SUNTANS model will be obtained from the high-resolution Luzon Strait Nowcast/Forecast System (LZSNFS), which computes the generation of internal tides and includes assimilated seasonal and mesoscale variability (Chao et al. 2014). The low-frequency variability from LZSNFS will be assimilated into the SUNTANS model using a novel scale-separation technique that assimilates low-frequency data without compromising high-frequency variability related to internal waves. Ultimately, because LZSNFS is also nested within Global HYCOM (Metzger et al. 2015), the proposed work will simulate surface-internal wave interactions through nesting of four models over spatial scales ranging from 1000 km down to 10 cm.

WORK COMPLETED

We use a high-resolution (~1.9 km) regional model to conneted Global HYCOM with very high-resolution (~100 m) nonhydrostatic SUNTANS and then to extrem-high resolution (> 1 m) LES. The regional model, the Luzon Strait Nowcast/Forecast System (LZSNFS), covers northern South China Sea and the Luzon Strait (Figure 1) where the large-amplitude nonliear internal waves are generated and propogating. The LZSNFS was developed for ONR NLIWI and IWISE, and has been shown to produce realistical large-amplitude internal waves compared to the obsercations (Chao et al., 2007; Ma et al., 2013; Pickering et al., 2015) and used for various internal waves studies (e.g., Qian et al., 2010; Simmons et al., 2011; Chen et al., 2013; Warn-Varnas et al., 2015). The LZSNFS was coupled to Navy's operational Global NCOM. Since early 2013, the Global NCOM has been replaced with Global HYCOM. The new procedure and scheme have been developed to coupled LZSNFS to the Global HYCOM.

A test run was conducted to evaluate the robust of coupling procedure and scheme. The Global HYCOM outputs, the operational product, were obtained from Naval Oceanography Office. The Global HYCOM fields are mapped to the high-resolution LZSNFS model for the boundary conditions (BCs). Since the operational Global HYCOM does not have tides, to produce internal waves, the tidal forcing are included in the BCs. For the borotropic velocity, u, at open boundaries,

$$u = (u_G + u_t) \pm c\,[(\eta_G + \eta_t) - \eta]/h,$$

where η is the sea surface elevation and c is the barotropic wave phase speed: $c = \sqrt{gh}$, with g being the gravitational constant and h the water depth. The subscript G denotes variables from Global HYCOM and subscript t denotes variables from tidal model.

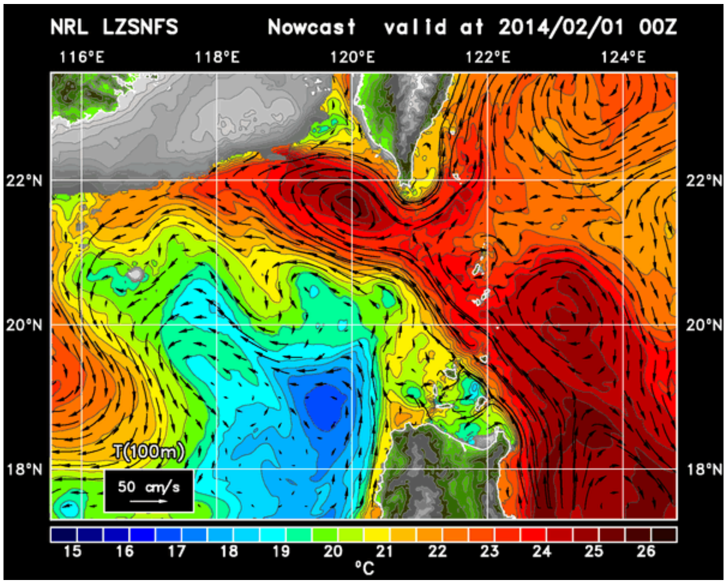

Figure 1. De-tided temperature and current at 100 m predicted by LZSNFS for 2014/02/01 00Z. It shows an intrusion of Kuroshio southwest off Taiwan as often obsevered during winter season.

RESULTS

A 1.5 year-long test run was conducted. Figure 1 show the de-tided temperature and current fileds at 100 m produced by LZSNFS with coupling to Global HYCOM. It shows rich mesoscale features such as the Kuroshio and eddies. An intrusion of Kuroshio is on the southwest off Taiwan as often observated during winter season. The instantaneous temperature field at 100 m (Figure 2) clearly shows the large-amplitude internal waves in the northern South China Sea and the influence of mesoscale eddies and currents. The robust of model coupling scheme can be clearly identified along the open boundaries that there is no noise or reflection even with strong inflow/outflow of currents (e.g., the Kuroshio) and outgoing of large-amplitude internal waves. A movie of the simulation can be downloaded (ftp://ftp7320.nrlssc.navy.mil/pub/ko/Model_Coupling.ppsx) for close examination.

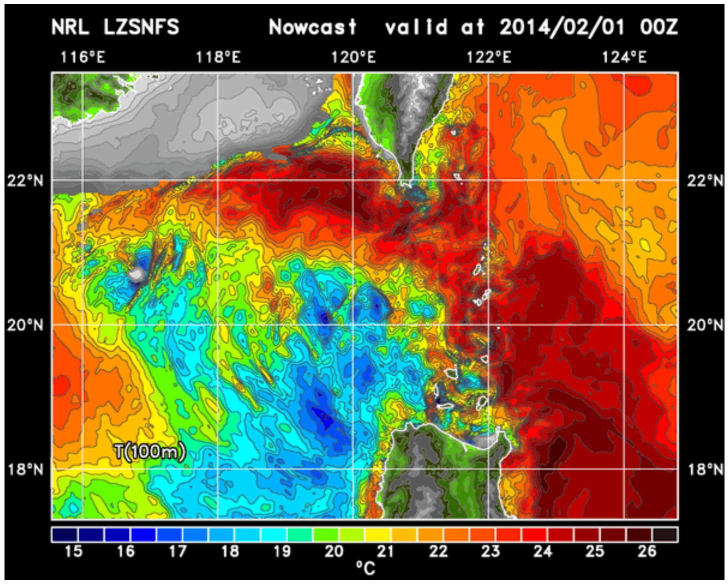

Figure 2. The instantaneous temperature field at 100 m (Figure 2) predicted by LZSNFS. It clearly shows the large-amplitude internal waves in the northern South China Sea and the influence of mesoscale eddies and currents.

IMPACT/APPLICATIONS

High-resolution simulations using nested, nonhydrostatic modeling frameworks such as the proposed HYCOM-LZSNFS-SUNTANS-LES nested model are crucial for understanding multiscale processes that are unresolved, and hence parameterized, in larger-scale ocean models.

RELATED PROJECTS

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